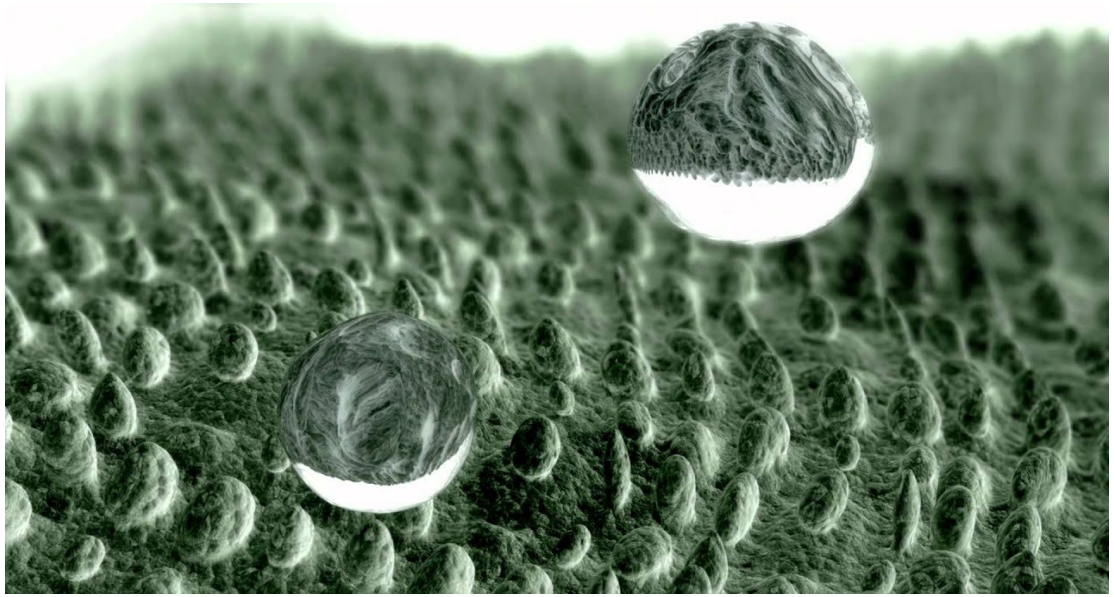
Biofilm Engineering Lab

Lepabe Laboratory for Process Engineering, Environment, Biotechnology and Energy

U.PORTO FEUP FACULDADE DE ENGENHARIA UNIVERSIDADE DO PORTO

# Development of nature-inspired surfaces to prevent biofouling in the food industry

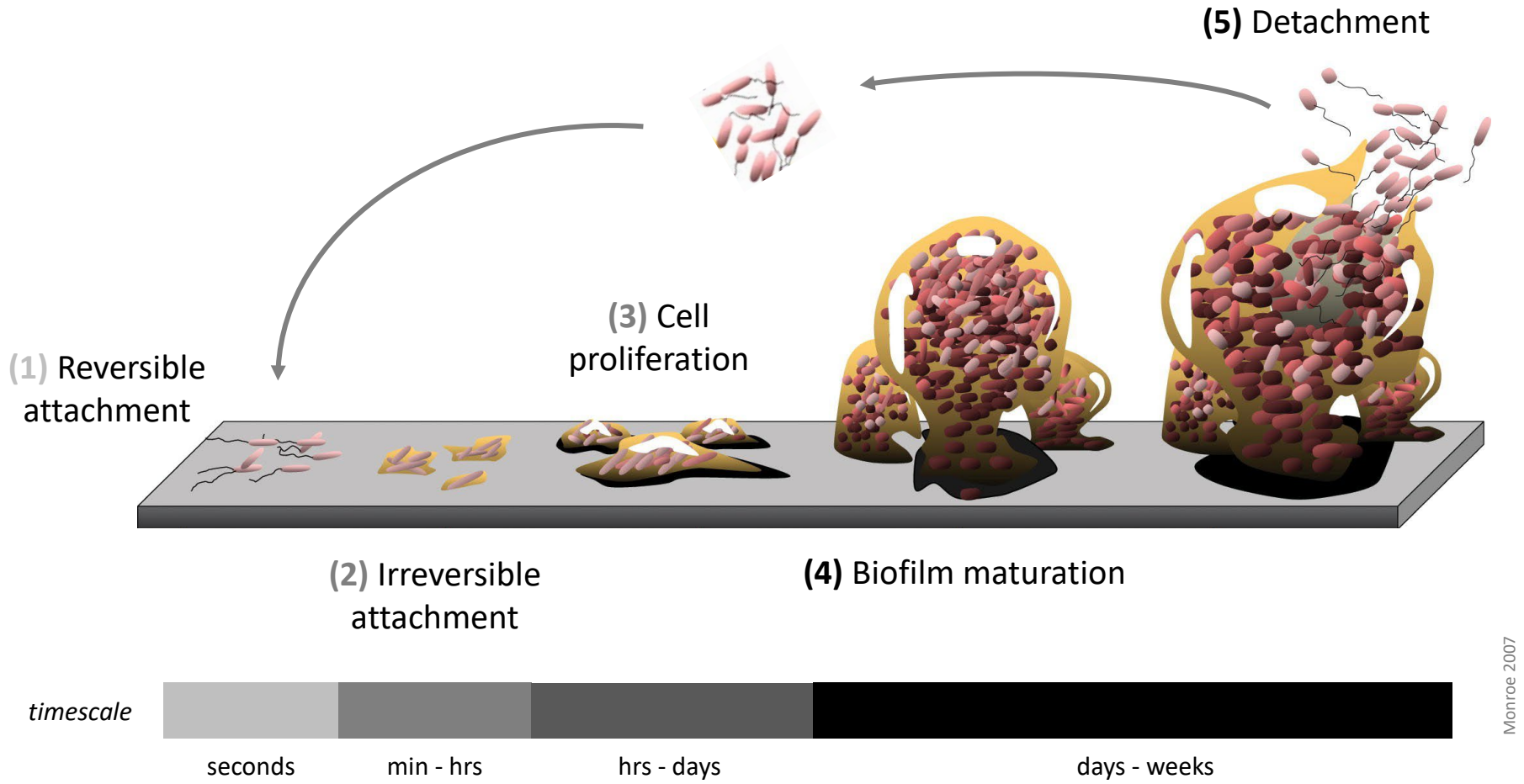


**LUCIANA GOMES**
Postdoctoral Researcher
(luciana.gomes@fe.up.pt)

ISEKI Food Association
Integrating Food Science and Engineering Knowledge Into the Food Chain

online conference, 11 November 2021

# Biofilms are complex and dynamic structures




Biofilms are communities of microorganisms which are protected by a self-produced matrix of extracellular polymeric substances

# Biofilms are everywhere…

**“Bad” biofilms**



*drinking-water distribution systems*



*food processing*



*industrial equipment*



*medical implants*



*ship hulls*

**Negative effects:**

- Pipe plugging, corrosion and water contamination
- **Decrease of industrial productivity due to equipment damage and energy losses**
- **Impact on the safety and quality of food products**
- Persistent and recurrent infections involving indwelling medical devices
- Increased corrosion, drag and fuel consumption related to hull fouling

# Factors influencing adhesion and biofilm formation

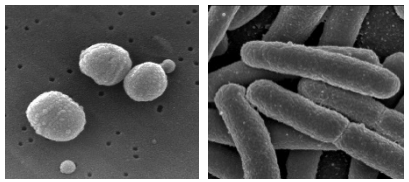


## Surface properties

- chemistry
- topography
- roughness
- hydrophobicity
- organic fouling

## Microbial strains

- cell density
- cell surface characteristics
- single or multiple species

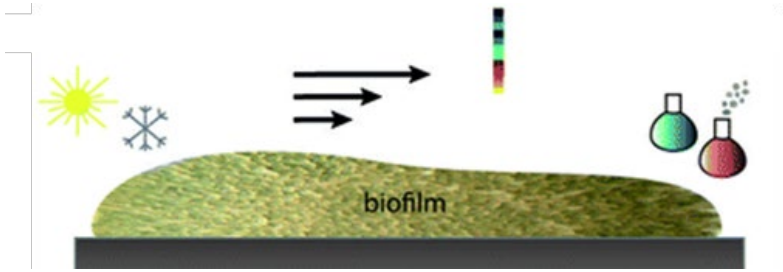


## Environment

- nutrient availability
- temperature
- pH

## Hydrodynamics

- flow regime
- flow rate
- shear forces



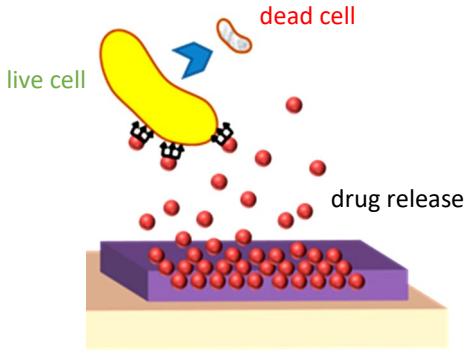

Understanding the mechanisms of biofilm formation is essential to **find efficient ways to promote or inhibit biofilm growth**

# Strategies to prevent biofilm formation

## Antimicrobial agents release

controlled release of high-local concentration of antimicrobial agents

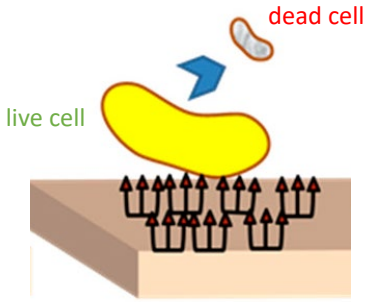
*(e.g., metals, antibiotics or bacteriophages)*




## Contact-killing

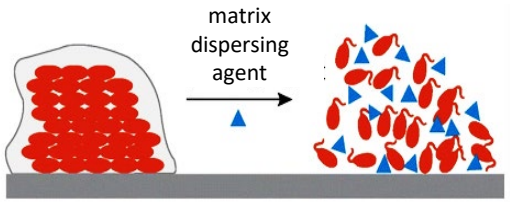
compounds immobilized on the surface

*(e.g., carbon nanotubes or graphene oxide)*




## Disruption of biofilm architecture

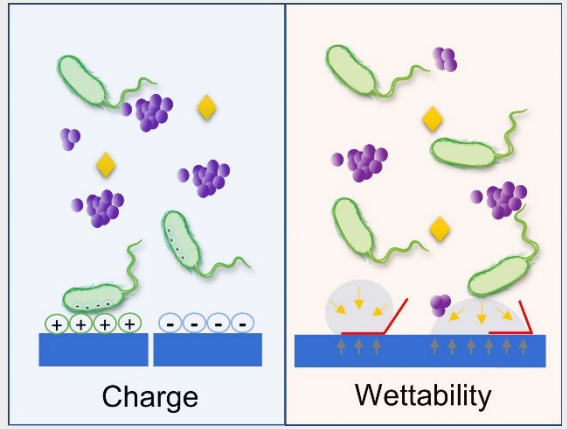
matrix degradation or QS interruption

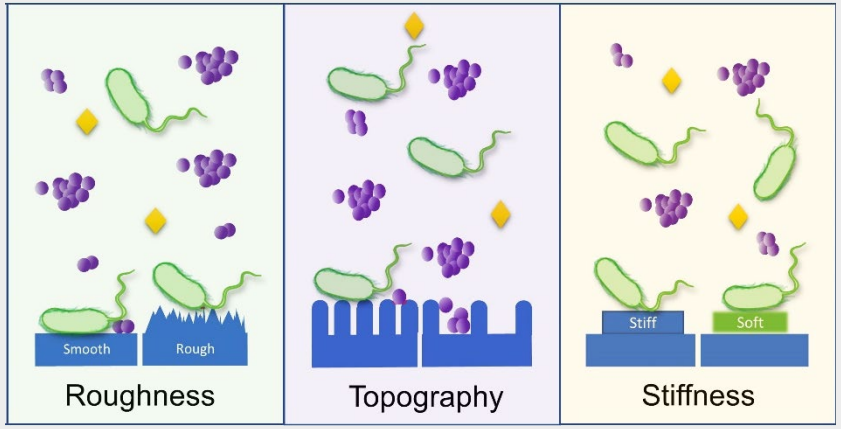



Andrade-Del Olmo et al. 2020; Azman et al. 2019

## Inhibition of microbial adhesion

**SURFACE MODIFICATION**




Zeng et al. 2021

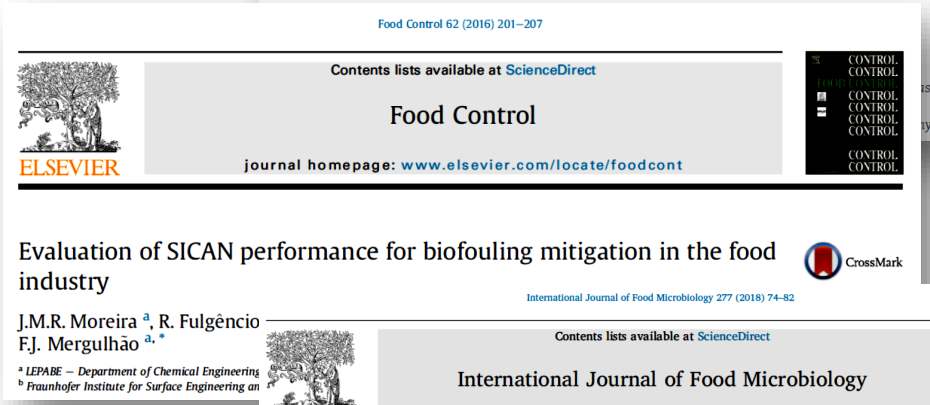
# Previous study on modified surfaces for the food industry



*e.g., fresh-cut vegetable industry*

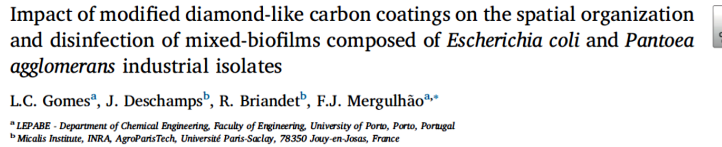
Biofilm formation on **food contact surfaces** is a major cause in **pathogen persistence** in food processing environments, leading to **economic losses** and **health concerns**









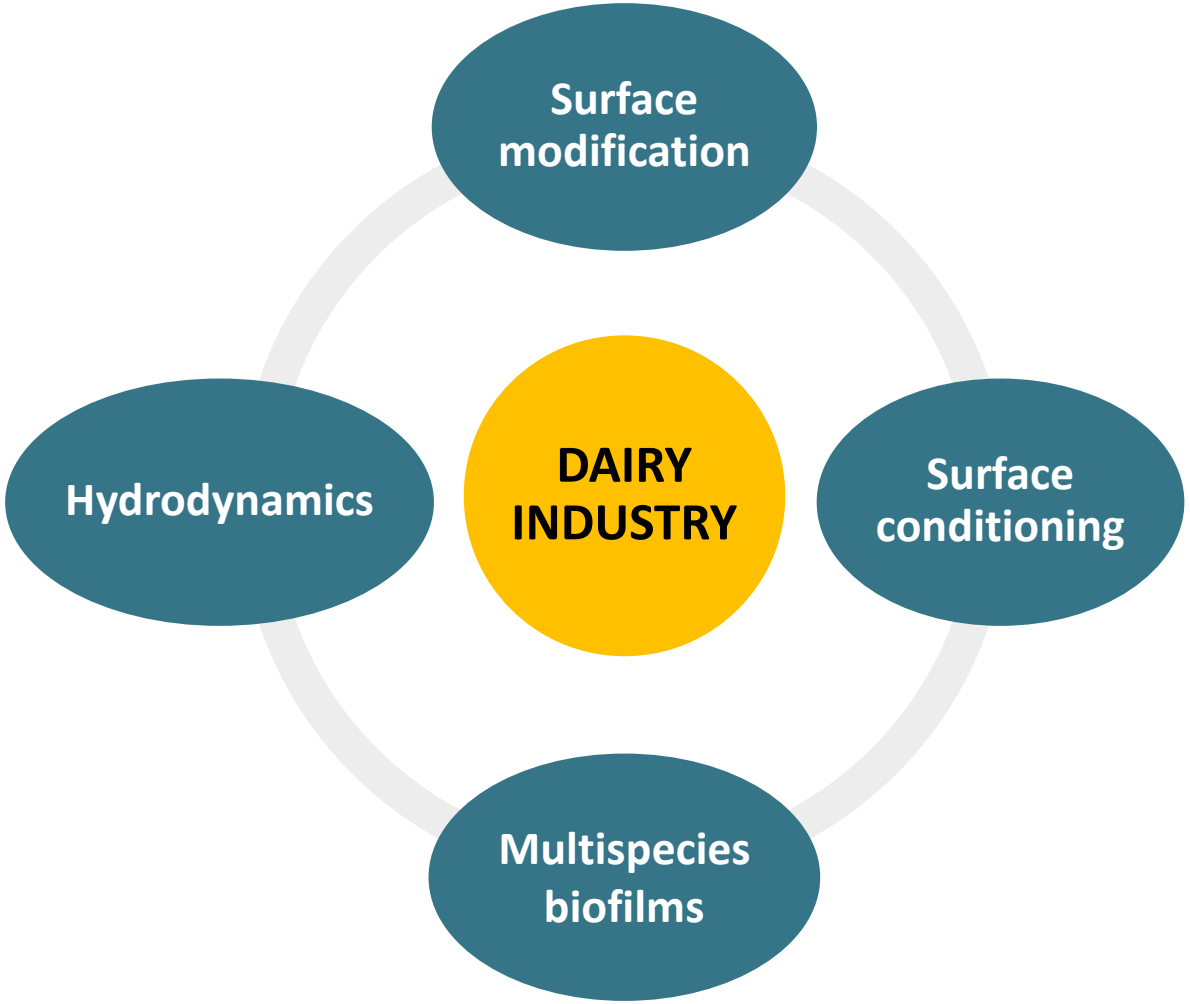

SUSCLEAN
SUSTAINABLE CLEANING AND DESINFECTION IN FRESH CUT FOOD INDUSTRIES



1) Characterization and monitoring of microbial contamination patterns
2) **Improving the hygienic design of equipment (geometry and surface)**
3) Designing new decontamination approaches for fresh-cut food and sanitation strategies
4) Proposing guidance and recommendations to renew the available processing techniques

**modified diamond-like carbon (DLC) surfaces**

## Surface modification to reduce microbial and organic fouling in the dairy industry






**INNOVATION:** integrated strategy

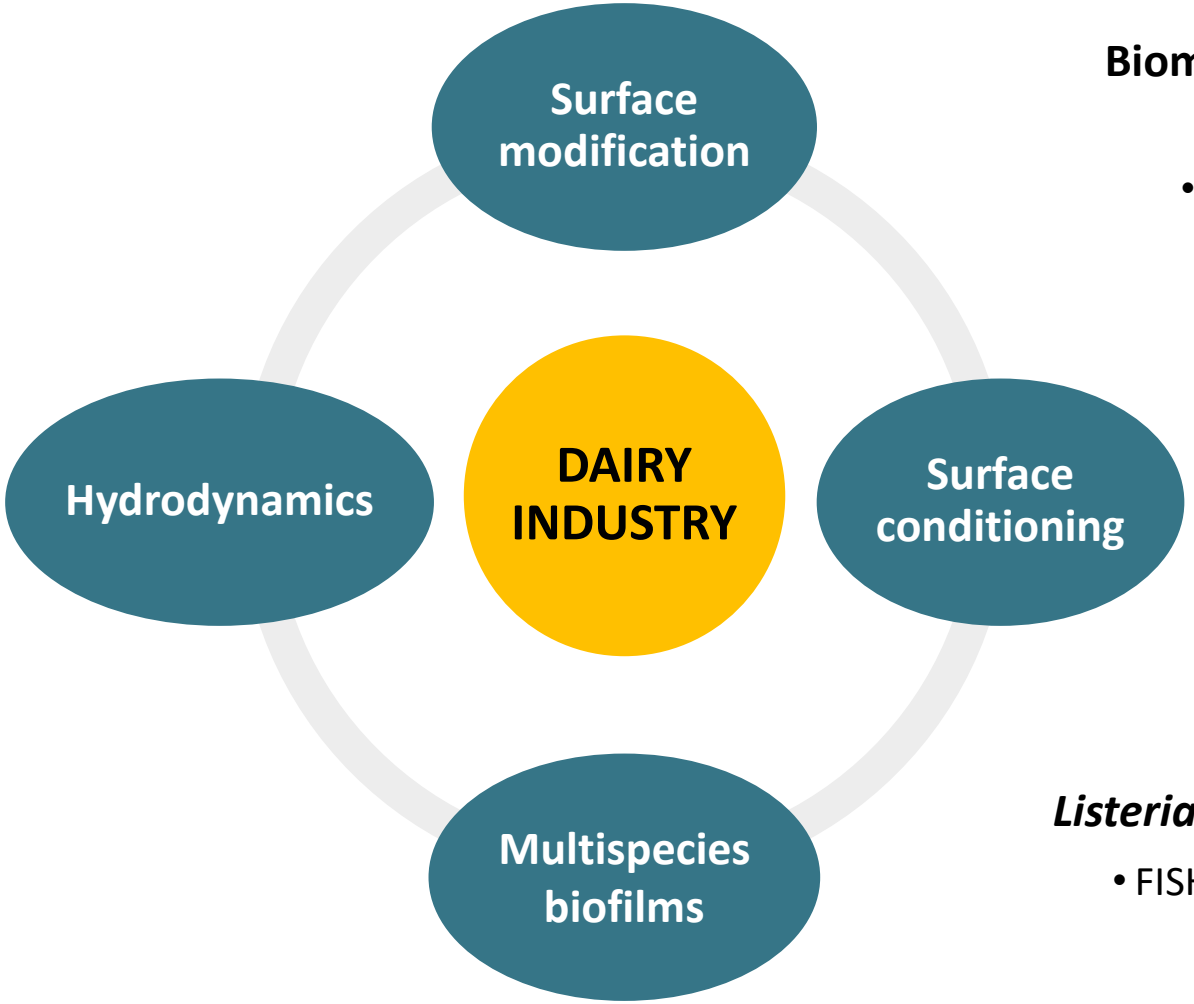


how surface modification affects conditioning and multispecies biofilm formation



find critical areas in processing plants that may benefit from the use of antifouling materials

## Surface modification to reduce microbial and organic fouling in the dairy industry




### Biomimetic polymeric surfaces

- surface topography
- surface physicochemistry

### Conditioning agents

- proteins
- carbohydrates
- inorganic salts

(etc.)

### *Listeria monocytogenes / Escherichia coli*

- FISH (fluorescence *in situ* hibridization)
- biofilm spatial organization

# First work on biomimetic surfaces

Contents lists available at ScienceDirect

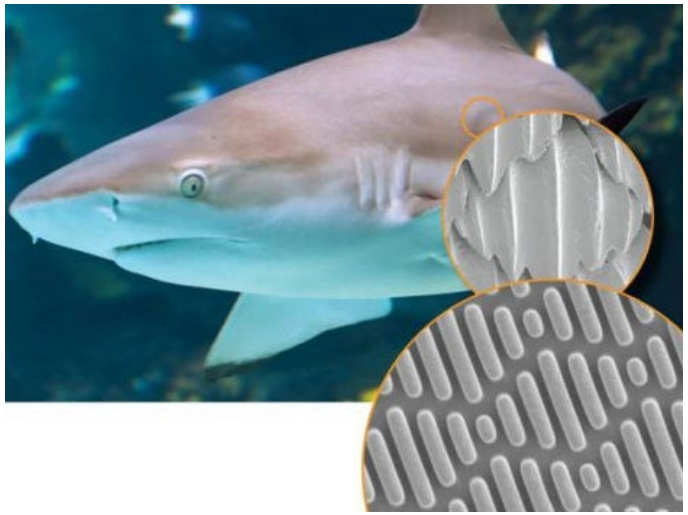
Colloids and Surfaces B: Biointerfaces

journal homepage: www.elsevier.com/locate/colsurfb

## Combining chemistry and topography to fight biofilm formation: Fabrication of micropatterned surfaces with a peptide-based coating

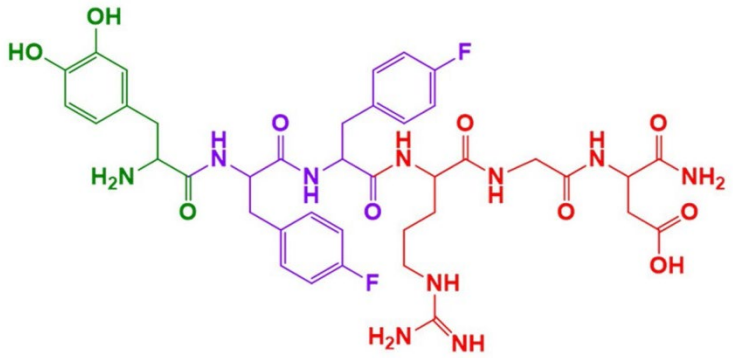
Alona Dolid [a,1], Luciana C. Gomes [b,1], Filipe J. Mergulhão [b,*], Meital Reches [a,*]

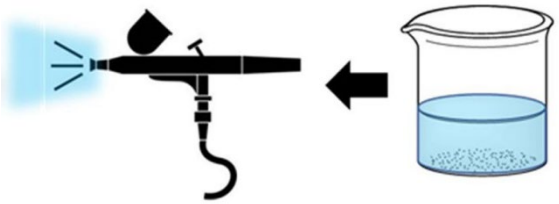
[a] Institute of Chemistry and the Center for Nanoscience and Nanotechnology, The Hebrew University of Jerusalem, Safra Campus, Givat Ram, Jerusalem, 91904, Israel
[b] LEPABE - Laboratory for Process Engineering, Environment, Biotechnology and Energy, Faculty of Engineering, University of Porto, Rua Dr. Roberto Frias, Porto, 4200-465, Portugal



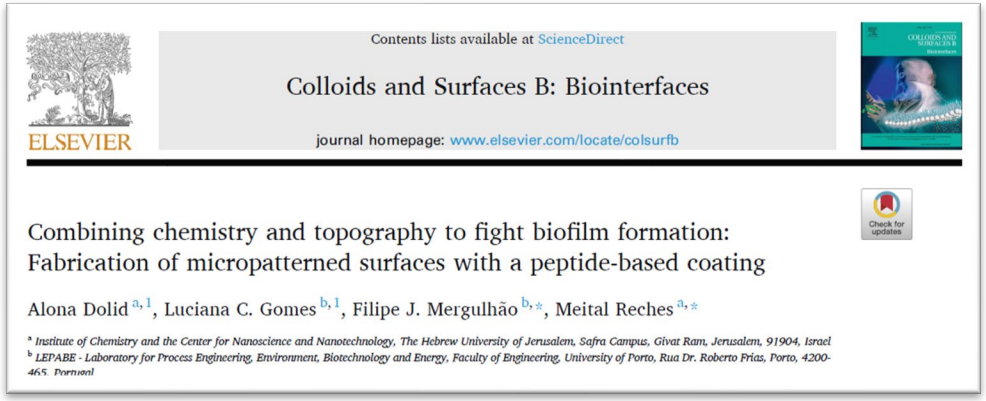
*shark skin surface*

*peptide*



# First work on biomimetic surfaces



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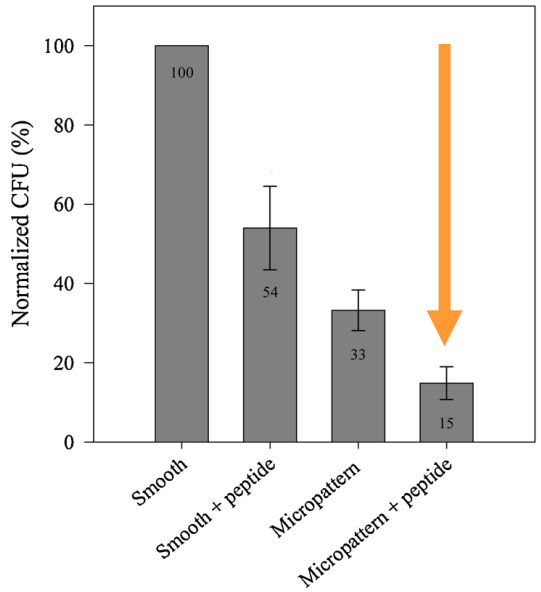
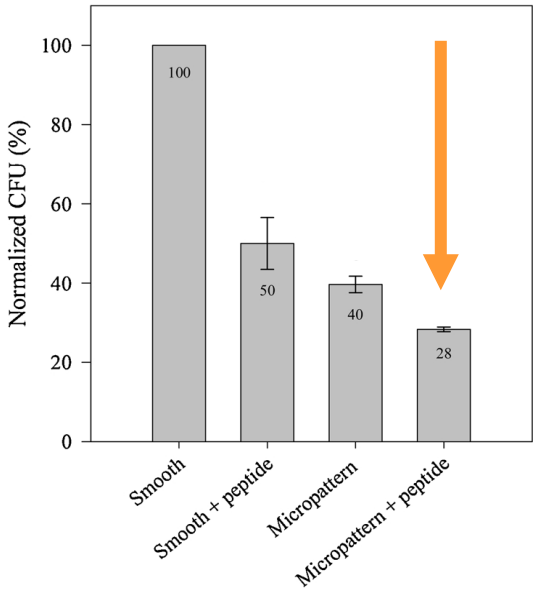
- **Static and dynamic assays**
- **22 h** of biofilm formation and **30 min** of adhesion
- Gram-negative (***E. coli***) and Gram-positive (***S. epidermidis***) bacteria

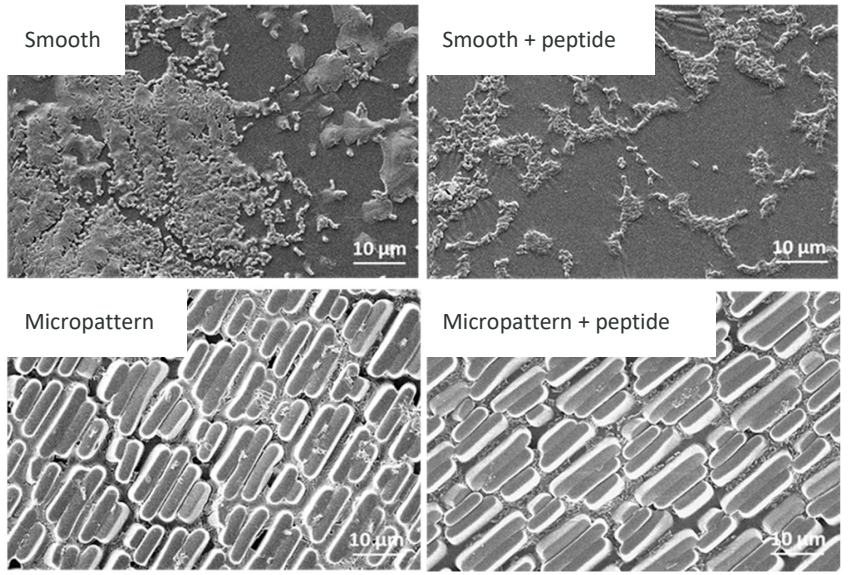
*E. coli*




*S. epidermidis*




**SEM images of *E. coli* biofilms:**




**The micropattern + peptide coating had higher antifouling properties**



# SurfSAFE project

**European Project approved within the Horizon 2020 call topic Widespread-05-2020, Twinning (2021-2023)**

Focused on the field of surface modification and biofilm analysis, necessary to enable development of **tailor-made antifouling and antimicrobial, non-toxic surfaces inspired by nature**

Surfsafeproject

SurfSAFE project

@SurfSAFE1

**surfsafeproject.eu**

# Consortium

SurfSAFE

**Coordination:**

**Faculty of Engineering - University of Porto (UPORTO, PT)**



**Filipe Mergulhão**



Kathryn Whitehead

**Manchester Metropolitan University (ManMet, UK)**

*surface engineering*

*biofouling*

*microbial interactions*

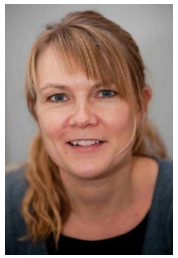
*hydrodynamics*

*biofilm analysis*

**University Medical Center Groningen (UMCG, NL)**



Jelmer Sjollema



Mette Burmølle

**University of Copenhagen (UCPH, DK)**

# Consortium

SurfSAFE

**Coordination:**

**Faculty of Engineering - University of Porto (UPORTO, PT)**

**Thematic Line 1:**

**Design, manufacture and characterization** of antiadhesive and antimicrobial surfaces

**Manchester Metropolitan University (ManMet, UK)**

**University Medical Center Groningen (UMCG, NL)**

**Thematic Line 3:**

Evaluation of the efficacy of antiadhesive and antimicrobial surfaces in the **presence of organic material**

**University of Copenhagen (UCPH, DK)**

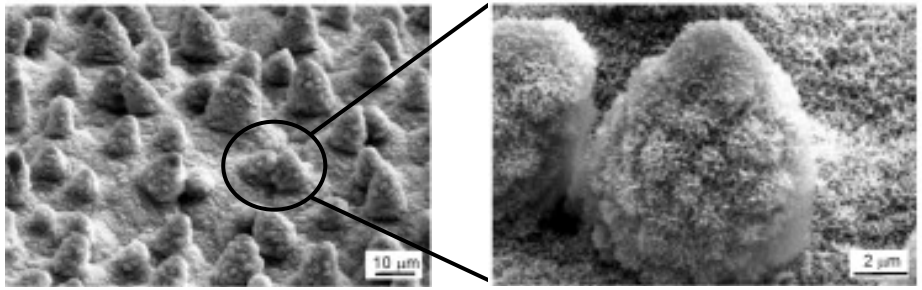
**Thematic Line 2:**

**Microbial interactions** in mixed biofilms and their impact on community survival and **horizontal gene transfer**

# Leaves as models for biomimetic surfaces

SurfSAFE

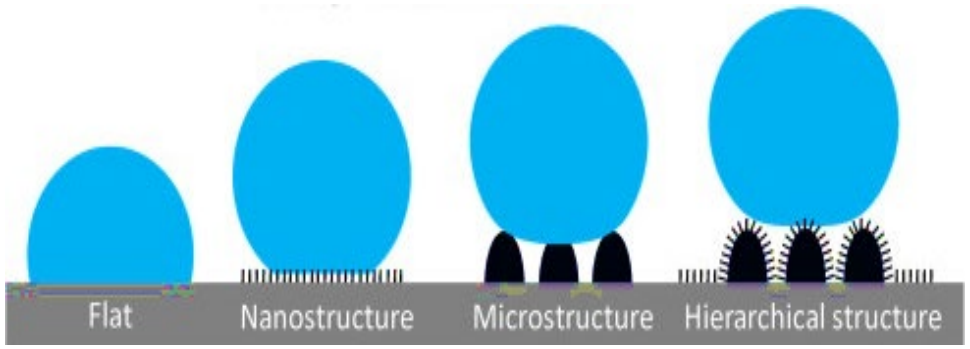
## Lotus leaf:






Bhushan and Jung 2011

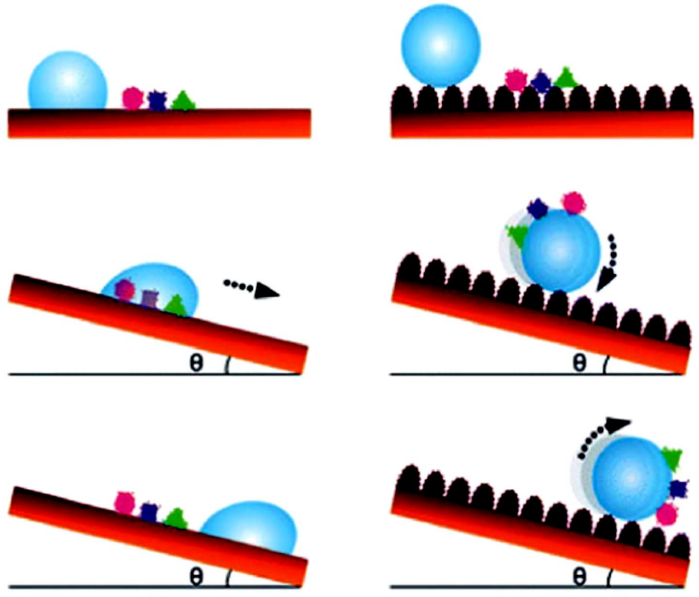
microstrutures with water-repelling nanostructured wax crystals




Bhushan and Jung 2011

**WETTABILITY**

flat surface | superhydrophobic surface

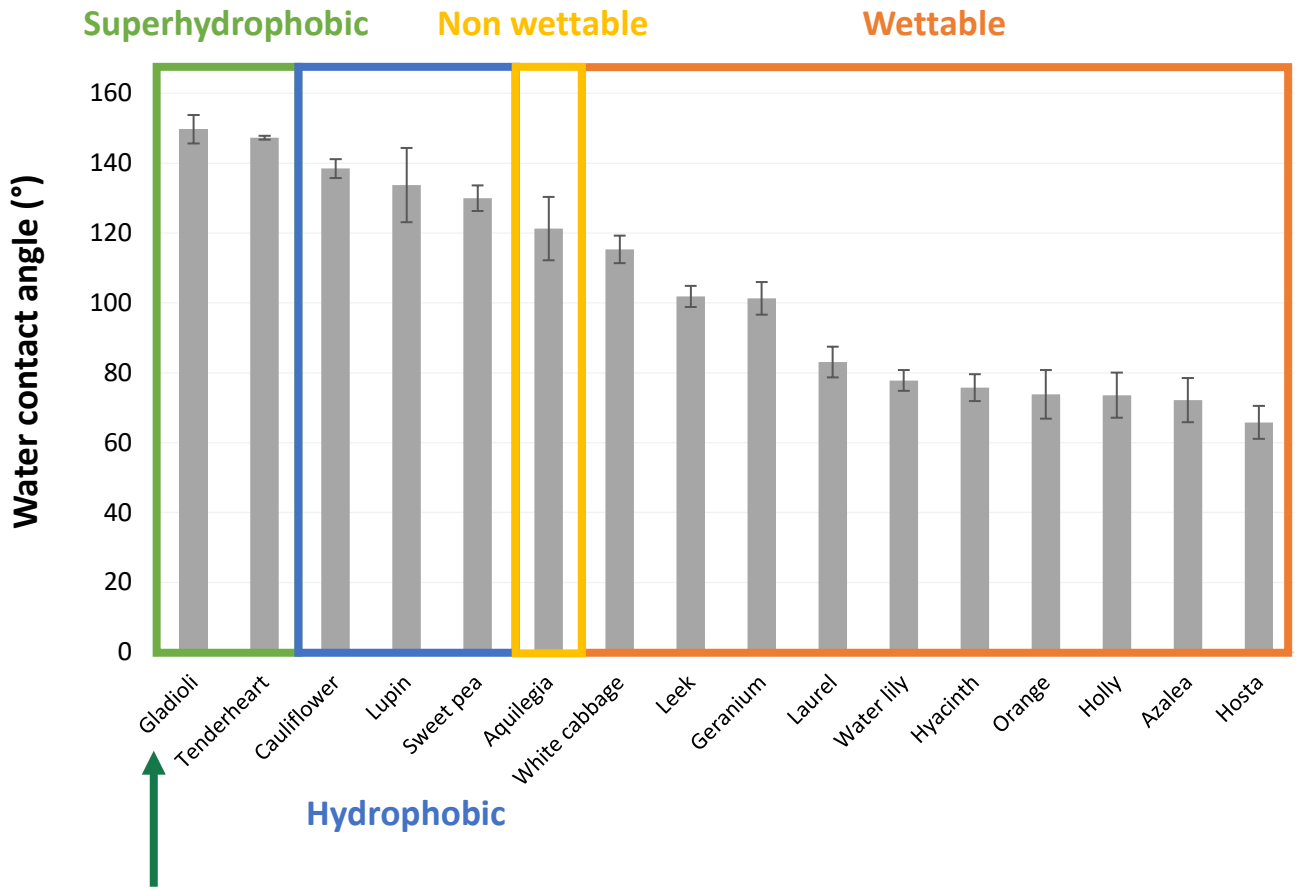



Darmanin and Guittard 2014

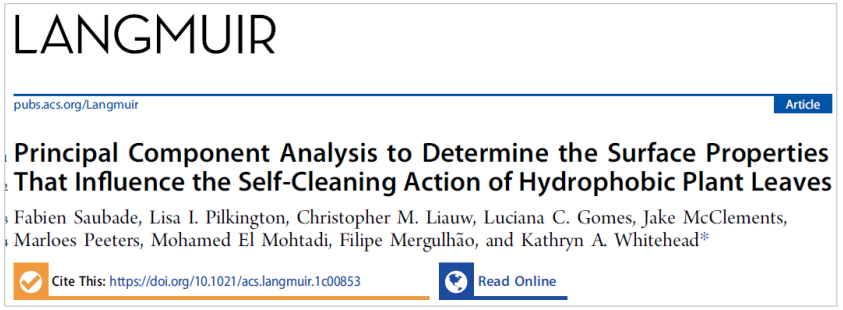
**SELF-CLEANING**

# Rationale

SurfSAFE




**Are the superhydrophobic leaves of Gladioli interesting to produce biomimetic surfaces?**


LANGMUIR

pubs.acs.org/Langmuir Article

**Principal Component Analysis to Determine the Surface Properties That Influence the Self-Cleaning Action of Hydrophobic Plant Leaves**

Fabien Saubade, Lisa I. Pilkington, Christopher M. Liauw, Luciana C. Gomes, Jake McClements, Marloes Peeters, Mohamed El Mohtadi, Filipe Mergulhão, and Kathryn A. Whitehead*

Cite This: https://doi.org/10.1021/acs.langmuir.1c00853 Read Online

Can hydrophobic surfaces be used to avoid bacterial retention, attachment and adhesion?

# Gladioli as a model for biomimetic surfaces

SurfSAFE

## 1. Fabrication process – Moulding & Casting

*Gladiolus hybridus*
(Gladioli)



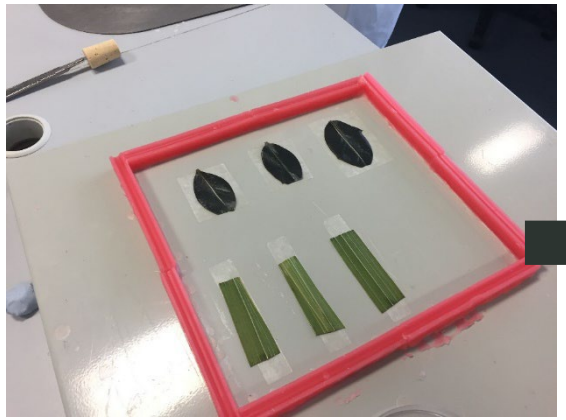
DE GRUYTER Pure Appl. Chem. 2021; ■■■(■■■): 1–12

Invited paper

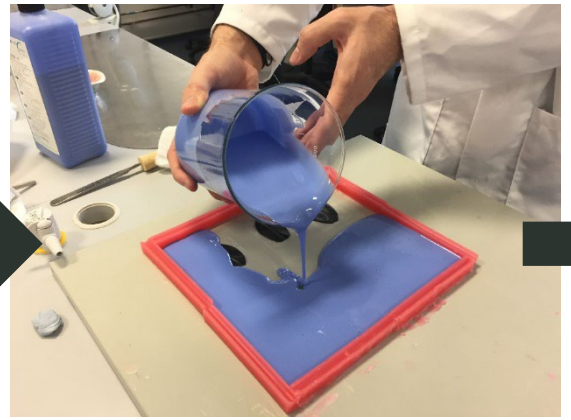
Jake McClements, Luciana C. Gomes, Joshua Spall, Fabien Saubade, Devine Akhidime, Marloes Peeters, Filipe J. Mergulhão and Kathryn A. Whitehead*

**Celebrating the centenary in polymer science: drawing inspiration from nature to develop anti-fouling coatings the development of biomimetic polymer surfaces and their effect on bacterial fouling**

leaf fixation



silicone pouring



negative silicone



wax pouring

**biomimetic surface**

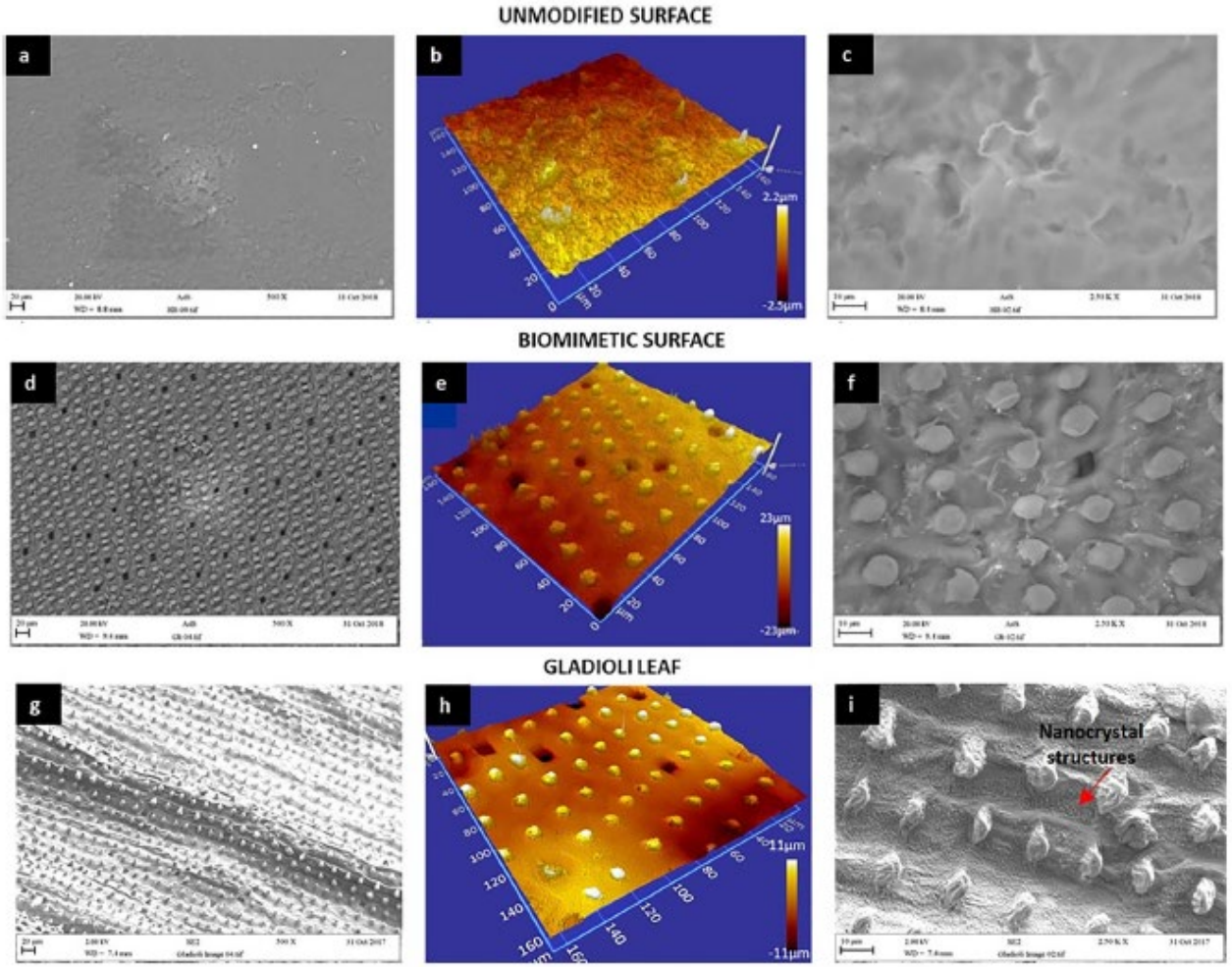


# Gladioli as a model for biomimetic surfaces

SurfSAFE

## 2. Topography and physicochemical properties

**SEM:** **Optical profilometry:**

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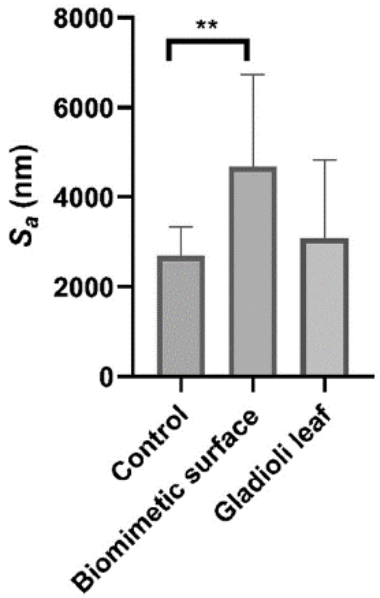
Biomimetic and leaf surfaces had **similar roughness parameters**…



# Gladioli as a model for biomimetic surfaces

SurfSAFE

## 3. Monoculture assays

> **adhesion assay** (spray)

> **attachment assay** (spray + $H_2O$ wash)





> **retention assay** (1 h bacterial incubation)

DE GRUYTER Pure Appl. Chem. 2021; ■■■(■■■): 1–12

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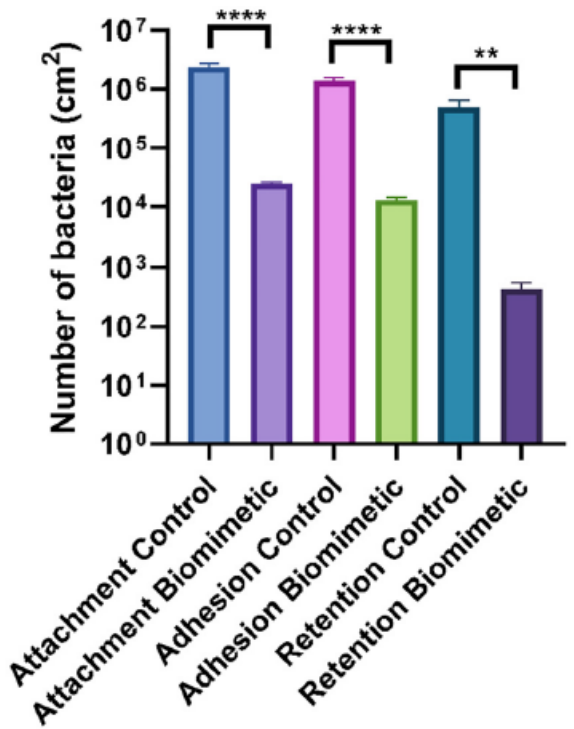
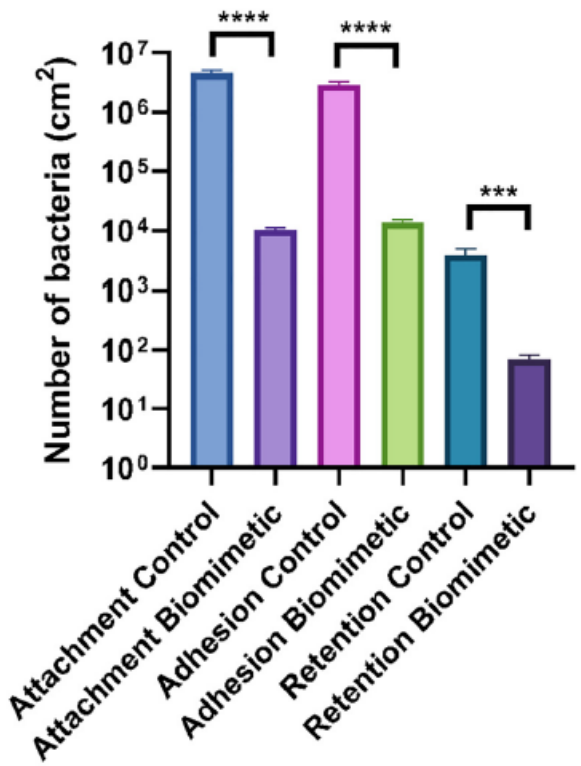
*E. coli*




*L. monocytogenes*




**Biomimetic surfaces had fewer bacteria than control** (unmodified surface)

# Gladioli as a model for biomimetic surfaces

SurfSAFE

## 4. Co-culture assays

> **adhesion assay** (spray)

> **attachment assay** (spray + $H_2O$ wash)





> **retention assay** (1 h bacterial incubation)

DE GRUYTER Pure Appl. Chem. 2021; ■■■(■■■): 1–12

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Jake McClements, Luciana C. Gomes, Joshua Spall, Fabien Saubade, Devine Akhidime, Marloes Peeters, Filipe J. Mergulhão and Kathryn A. Whitehead*

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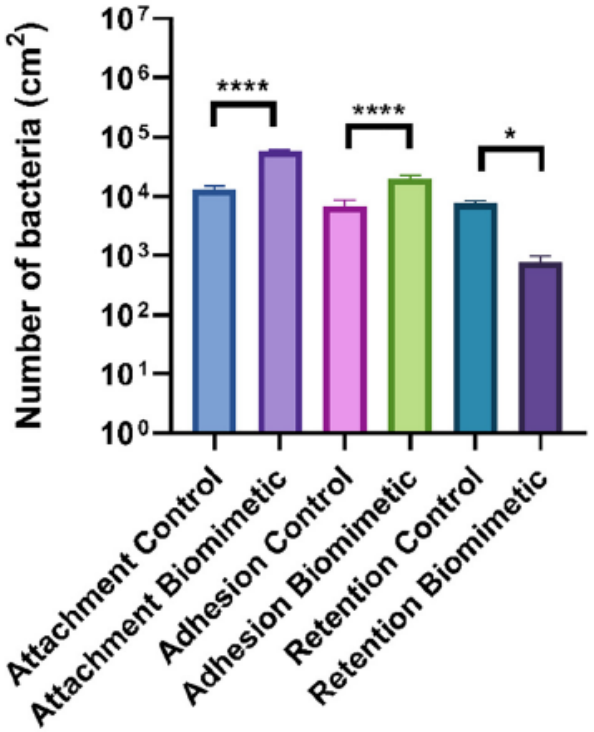
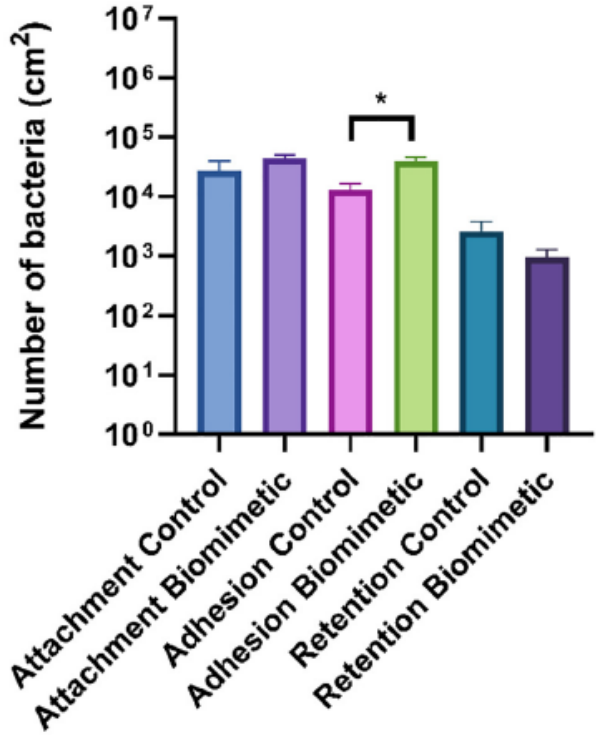
*E. coli*




*L. monocytogenes*

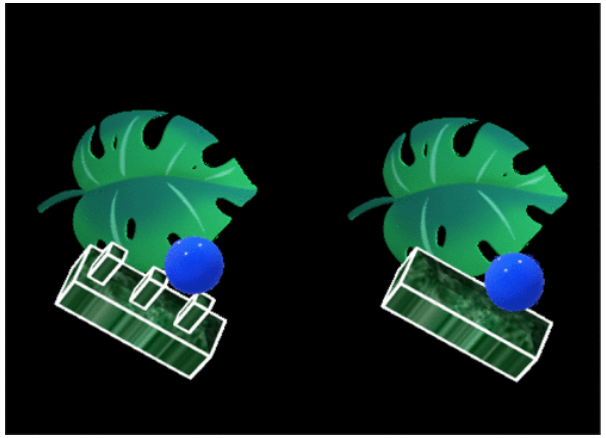



**Bacterial numbers were reduced on biomimetic surfaces only following retention assays…**

# Take home message

SurfSAFE

- Self-cleaning **biomimetic surfaces** can be of **great benefit to human health**, in addition to **reducing the economic burden on industries**.
- It is known that **many plant leaves display self-cleaning properties**, being promising surfaces to mimic.
- Understanding the **interplay of surface properties** **(topography, chemistry and physicochemistry)** is extremely important to **produce optimized biomimetic surfaces**.
- Such biomimetic surfaces may be effective in reducing biofouling if used in the appropriate medical, marine and industrial scenarios.



**Scientific support**:

Prof. Filipe Mergulhão & Prof. Kathryn Whitehead

Microbiology at Interfaces Group @ MMU

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FCT Fundação para a Ciência e a Tecnologia
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# THANK YOU!

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